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ABSTRACT

This discussion of the development and application of lasers and microprocessors to information processing stresses laser communication in relation to capacity, reliability, and cost and the advantages of this technology to real-time information access and information storage. The increased capabilities of microprocessors are reviewed, and a general assessment of the impact of these technologies is provided. (RAO)

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Information Technologies for the 1980's: Lasers and Microprocessors

by

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INTRODUCTION

I have been asked to speak today about lasers and microprocessors, about their impact on information processing generally and on the library in particular. I will begin with a sketch of the state of the art in which I will describe the present information processing applications for these two inventions. I will then mention some steps we might take to better assimilate these technologies into the library community. While my topic is basically technical, I shall avoid technical details whenever possible.

Twenty-one years ago the most intense technological struggle in modern times was underway. It was 1958, the first full year of the "race for space." Dogs and monkeys were orbiting the earth.

Two other technological events occured that same year, but these went largely unnoticed. The first of these was outwardly marked by a patent application and a subsequent article in Physical Review that described what would one day be called the "laser." Within two years a working model was demonstrated publicly, and since that time lasers have found their way into a remarkable variety of applications in medicine, manufacturing, industrial research, and of course, in information processing. The laser, it seems, has exhibited the infinite variety inherent in a beam of light itself.

Also in 1958, significant refinements occured in quite another area of endeavor. In the autumn of 1958 the world's first integrated circuit was created, unlocking the door to a sequence of innovation which continues today. With each step we witness more complex and intricate circuits in smaller and smaller physical packages. For the most part these are constructed on a wafer of silicon--one of the earth's more abundant elements--the makings of ordinary sand.

These two events, as I have said, occured twenty-one years ago. So in some sense we might well expect that these inventions have "come of age" today. Indeed they have. Laser and microelectronic technologies have both matured, and the application of these technologies is beginning to have a profound affect on information processing, the basic business of libraries.

I am further reminded that today we are twenty-one years away from still one more event: the end of the twentieth century. It is with the sense that we are poised midway between the birth of these inventions and that important psychological turning point, the end of an age, that I will frame my remarks. From time to time I will attempt to envision what might happen twenty-one years from now, though these views are rather intuitive, and are by no means precise. With that, I will commence to describe the possibilities in something so deceptively simple as a beam of light and a grain of sand.

LASER APPLICATIONS

The laser is conceptually such a simple device that one might well say as Francis Bacon remarked of movable type "It appears at first incredible that any such discovery should be made, and when it has been made, it appears incredible that it should so long have escaped men's research." I would like to discuss two principal areas of laser application: communication and storage.

LASER COMMUNICATION

Communication over fiber optic links is the fastest-growing application for lasers today. Fiber optic cable has many advantages over wire cable. These relate chiefly to capacity, reliability, and cost.

--Regarding capacity, a single filament of optical cable, as thin as a human hair,' has the same information carrying capacity as a copper cable several millimeters across. In fact, an amount of fiber optical cable that could easily be held in one hand can replace several tons of copper wire.

--With respect to reliability, fiber optic links are immune from electrical noise. This is especially important in industrial settings. There are no problems with crosstalk. And solid state lasers with an operating life of more than million hours are now being introduced to drive these fiber optic links. This means that communication links with orders of magnitude greater reliability than conventional links can now be placed in service.

--And finally, when it come to cost, shipping, handling, and installation costs for fiber optic links are lower due largely to reduced weight. Manufacturing costs are presently still somewhat higher than copper cable but these costs can be expected to drop rapidly as production volume grows, while costs for copper cable continue to rise as copper becomes more scarce.

Following a highly successful interoffice optical trunk installed by AT&T in Chicago, at least twenty other links are being implemented in the United States today. For the most part these links replace common carrier network trunks, but also included are several cable television feeds, an entire 10,000 subscriber telephone exchange in Florida, and a communications link in a San Francisco Transit tunnel. This last is a good example of an application in an electrically noisy environment; the optical cable is installed alongside a power line. In Canada, where proportionately more people receive television signals through cable than anywhere else in the world, heavy emphasis has been on optical cable television. In Ontario a digital television link has been installed,and implementation of a fairly extensive fiber optic system in Alberta is underway. Perhaps the most comprehensive system of all is being planned for Japan where it is expected that a system of interactive fiber optic cables will carry a wide variety of information into the home. Other systems are in place in Frankfort, Germany, Brussels, Belgium, and are in the planning stages in practially every other developed country. Within five years most new intercity trunk facilities installed in telephone networks will be optical links. Because of the present high cost of optical switching and terminating devices, applications will be limited at first to these intercity and interoffice connections.

But ten years from now, with further development of integrated optical switching circuits, broadband optical links directly to the home will

become economical and practical. When this happens, a single link will simultaneously support many television channels, high-fidelity music, news, information, computer interactions, facsimile, and of course voice transactions.

In related developments, do-it-yourself optical links are now readily available. For a few hundred dollars a digital data link between computers can be built. Also some computer manufacturers are using optical links to communicate between mainframes and peripherals. Moreover, AT&T recently developed components around which a light-powered phone can be built. Any power needed for electric circuitry and to ring its bell will be converted from light received over the optical link.

SIGNIFICANCE OF LASER COMMUNICATION

The significance of this increased communications capability is that it will establish a climate in which real-time information access will be a common expectation. Distribution networks, tailored to specific needs and clienteles, will transmit electronic news, mail, banking and library services directly to the consumer. Invisible colleges, using these personalized networks to converse and exchange information will inevitably result. Further, broadcasting will yield to narrowcasting and more discrete communication modes. In the next century, as optically linked cities and 'wired nations' emerge, our planet may once again become quiet in the electromagnetic spectrum. No longer will we squander energy by radiating information indiscriminately into outer space.

LASER STORAGE

Now I should like to turn away from laser applications for communication and comment on the state of the art regarding laser applications for information storage.

For many years the laser has seemed to be an ideal component to use in an information storage system. Because of its coherent radiation, it can provide a very well focused source of light which has the power to write very precise patterns of information onto materials and to read the information back again. Two chief lines of systems development have been pursued: one based on holography, and the other relying on bitwise storage of information, generally on tracks of a disk.

The idea of holographic storage is particularly captivating because:

--first, holographic systems tend to be inherently redundant. Part of the recording medium can be damaged or destroyed without data loss.

--second, holographic techniques provide parallel access to very large amounts of information at one time. And,

--third, truly incredible recording densities can be achieved. Using a three-dimensional crystal as a recording medium, for example, distinctly different information patterns can be recorded by changing the orientation of the recording medium by as little as one degree. Multiple images, each containing

many millions of bits of information, can thus be recorded in a single physical medium.

Holographic storage systems are still for the most part in the prototype stage and are not yet ready for widespread use. There are two principle technical reasons for this:

--first, although the laser itself is a simple and elegant device, quite complex mechanisms called 'page composers' and 'page detectors' must be used to read and write the holographic storage device, and

--second, the search for an ideal storage medium seems to be a never ending quest. This is due in no small part to the extraordinary requirements placed on such a material: It must have great photographic sensitivity and high optical resolution. The image must develop and stabilize within a few thousandths of a second without the assistance of a chemical developer or fixative, yet the image must be relatively permanent and not readily decay. But also the image must be rapidly switchable, that is, it should be possible to selectively erase and rewrite. Further the material must be dimensionally stable, not easily distorted by thermal or mechanical stress.

No single storage medium combines all these properties and an astonishing variety of materials have been tried. These include 'photochromic' materials whose absorption at specific wavelengths can be rapidly

modified; 'photoconductive' materials which build up a charge of excess electrons when exposed; 'thermoplastic' materials which can be optically deformed; 'ferromagnetic' and 'ferroelectric' materials in which polarization patterns can be frozen at appropriate writing temperatures.

While the widespread application of holographic storage is still a few years distant, laser storage systems based on bitwise recording of data are truly at hand and readily available. The videodisk is the primary example of this technology. Most of the disks now available are not erasable, but that may be of little importance for library applications. The master disk is recorded by laser and subsequent copies can be created by a technique quite similar to pressing phonodisks. And at comparable costs. The copies are read on a playback device which employes a laser in its detection system as well. The stimulus for this development came from the consumer electronics market and the desire to playback movies on television. But the storage system can be used for digital data as well as video.

A single disk can hold several thousand high-resolution color photographs, 50,000 color television frames, facsimile images of several hundred thousand documents, or perhaps more than a million bibliographic records recorded in digital form. Recording densities as great as 10^9 bits per surface will be introduced in the near future.

Bitwise recording may, in fact, supercede holographic techniques for even the largest storage systems. IBM has recently proposed a bitwise system built around a tunable laser which may be able to record 10^{11} bits per square centimeter. The storage medium would be sensitive to a great many wavelengths at each point, and atomic color centers would be used as the information store. Now 10^{11} bits is quite a lot of storage by almost any measure. Physiological evidence seems to indicate that the human brain contains something on the order of 10^{13} memory cells. At these recording densities, the memory content of the human brain could fit on a surface no larger than a single library catalog card. By the end of this century a system of this kind may well be operable. Even using fairly sloppy scanning and data compression techniques, the entire contents of the Library of Congress could fit on a few square meters of surface area.

SIGNIFICANCE OF LASER STORAGE

The significance of this and similar developments in electronic storage is that for the first time it is now more economical to mass-produce a data base and distribute multiple copies in machine readable form than to print and distribute the average reference book. Large amounts of reference information, especially information for decision-making, will be distributed in this new form. The traditional linkages between the publisher and the user will radically change as electronic distribution redefines the bounds of the publishing industry. Unwieldy and cumbersome micropublishing ventures will also convert to this medium. Already, a bank in the United States has replaced a microfilm record of its daily transactions with a videodisk system. By the end of this century, the amount of information in these digital stores will exceed the amount of information stored in libraries. The data will be accessible in a matter of milliseconds, not hours or days. And it will form the basis of personal libraries of remarkable size.

There are a great number of other applications of the laser in platemaking for the graphic arts, in optical scanners for computer input, in computer printers, and so forth, but I would like to pass over these and move immediately to the topic of microprocessors.

MICROPROCESSORS

If it could be said of the laser that, once invented, it somehow 'appears incredible that it should so long have escaped men's research,' the microprocessor is quite the reverse. The more we study the microprocessor, the more awesome and incredible it becomes. Nothing about this invention seems obvious, for it represents the confluence of the inventive genius of many different disciplines--physics, electronics, mathematics, and chemistry--all brought together in an invention so small it requires a microscope to see its details. The microprocessor is destined to have a greater impact on more people in this world than any other technology ever conceived.

Microprocessors are attractive because they allow design flexibility together with systems elegance. Also, their simplified physical packaging brings about greater reliability. Environmental requirements are a factor too: microprocessors use less energy, produce less heat, and seldom need elaborate air conditioning. Cost, of course is perhaps the most significant point. With economies of scale the cost of a microprocessor continues to decline.

Only a few years ago, the microprocessor was relegated to relatively simple tasks--driving intelligent terminals, or providing the 'brains' for a hand-held calculator. Now however, with the introduction of very large scale integration (VLSI), microprocessors are taking on many of the functional attributes formerly expected only in very large computers.

Some impressive capabilities have begun to emerge:

--microprocessors that can be readily altered to execute the instruction sets of a variety of other predefined machines.

--microprocessors that directly execute higher-level languages such as COBOL--heuristic microprocessors that learn from their environment.

--configurations of microprocessors so sophisticated that they can detect and analyse failures within their own circuitry and call upon redundant processors to begin work where the failed processor left off.

--loosely coupled microprocessors with distributed operating systems and distributed computational responsibilities.

--home computers built from microprocessors, the entire system no larger than a suitcase, making more computing power available to the individual than could be obtained from a computer that filled an entire room a few years ago.

Apparently the steady progression toward faster circuits in smaller and smaller packages has still some way to go. Preliminary investigation of Josephson junction devices, presently objects of intense research, indicates that computers some 50 times faster than the fastest computers known today may be possible. By the end of this century, using this technology, computers more powerful than any presently in existence might be no larger than a grapefruit.

SIGNIFICANCE OF MICROPROCESSORS

The significance of this rapid development in microelectronics is that it is now more practical to bring the computer to the problem than to bring the problem to the computer. In the past, we have been accustomed to allocating computer time carefully, so that this relatively precious resource should not be wasted. In the future we will dedicate computers to relatively simple tasks, with little concern for their full-time utilization. By the end of this century there will be more microprocessors than people on this earth. Simple microprocessors will be used to control almost every electrical device, more complex ones will be in our automobiles, and thousands of microprocessors all working together will be used in multipurpose computers.

ASSESSING THE IMPACT

How should we understand these developments in communication, storage, and information processing? And how can we learn more precisely the implications for the library?

Taken one at a time, and extrapolated only a short distance into the future, each development seems understandable enough:

--new communications capabilities will broaden our access to real-time information; broadcasting will change.

--new storage capabilities will alter the distribution of data bases and reference materials; publishing will change.

--new processing capabilities will make personal computing a reality; computing will change.

But taking all three of these trends and extrapolating them to the end of the century gives us a vision of the future that seems incomprehensible and senseless. We are confronted with a glimpse of someone casually walking down the street with an archive the size of the Library of Congress neatly tucked into a shoebox, a computer no larger than a pack of cigarettes for accessing this collection, and a length of optical fiber that looks like a spool of thread but has the information carrying capacity of a truckload of copper wire. Intuitively we know something is wrong, for, even today, libraries can hardly afford to buy the shoes that should have been in the shoebox in the first place.

Basically, what we are dealing with is the extrapolation of three sets of exponential cost-performance curves. Communication capacity is increasing while costs decrease. Storage performance is increasing while costs decrease. Processing power is increasing while costs decrease. In each case there is an order of magnitude improvement in cost-performance every five to ten years. Taken together the three curves portend an embarrassment of riches--communication systems that deliver more information than anyone could ever want, storage systems for archives we could never hope to read, computer systems that could process information more ways than we can possibly comprehend.

Intuitively, as I have said, we tend to discount this version of the future as astounding and far fetched. After all, other extrapolations, in other disciplines, seem to indicate a future world of shortage and poverty--too little energy to run our industries, too little food to feed the hungry. The notion that we should have an abundance of information capabilities in the face of such shortages, seems disturbing and unpalitable.

Frankly, a coherent metasystem that encompasses communications, storage, and processing might never evolve; but then again it might. The important thing is that right now we do not have enough facts to know, and we cannot reasonably envision the library's future given that unknown.

This leads me to my proposal: A thoughtful and comprehensive technology assessment must be performed to closely determine the impact these electronic and optical developments will have on the library world. Like any good technology assessment it should analyse the political, economic, and social realities together with the technology. And such an assessment should be international in scope taking into account the global interests represented at a meeting such as this. We should stop presuming that someone else will do this work for us, the initiative should begin right here.

I have a further suggestion that bears on how the technology assessment should proceed. Instead of looking at trends and tendencies, the assessment should focus on constraints and discontinuities. Mathematicians and scientists have made us feel complacent about rapid change. They have a disarming and beguiling way of dealing with growth. They take out a sheet of 'log-log' graph paper and draw a few straight lines. Thus exponential growth is robbed of its meaning and made to look like an ordinary thing. But nothing grows exponentially forever. And even the slightest wiggle on this kind of graph paper can indicate a genuine discontinuity beyond which we must alter our beliefs. The theoretical basis for investigating phenomena from this point of view is laid in part in a recent book entitled Catastrophy Theory which states in its opening remarks: "Catastrophe theory is a controversial new way of thinking about change--change in a course of events, change in an object's shape, change in a system's behavior, change in ideas themselves.

Its name suggests disaster, and indeed the theory can be applied to literal catastrophes such as the collapse of a bridge or the downfall of an empire. But it also deals with changes as quiet as the dancing of sunlight on the bottom of a pool of water and as subtle as the transition from waking to sleep."

The book goes on to deal with some everyday catastrophes we are all familiar with, unthinkable events that now seem all too evident: the effect of an oil cartel on the use of energy; the effect of a nuclear power disaster on public attitudes toward plant construction. In each case we learn to distinguish the difference between rapid change and true discontinuity; the difference between a ski slope and a cliff.

I think that we are fundamentally at a similar point with respect to information technologies. We feel that the technologies I have spoken of today will have a profound influence on the library. Its institutional role, and its function in society will undoubtedly change. But the forces at work are both subtle and obvious, elusive yet dominent. This is why I encourage you to consider technology assessment from this particular point of view. With an adequate assessment of the technology we will be able to detect the edge of the cliff and learn to see beyond.